Exploring the New Frontier:

The Search for Life on Mars

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Introduction

Are we alone in the universe? It is a question that has long been on the mind of humans. Out of this kindle of curiosity sparked entire religions, cultures, and even the scientific facts that we follow today. The more we fuel and dwell on this curiosity, the more we crave the answers to our deepest questions. Is it possible that our planet is unique? Probability says no. In 1961, a Harvard astronomer named Frank D. Drake devised a formula that could estimate the "number of communicative extraterrestrial civilizations" that could possibly exist in the Milky Way (BBC, 2012, August 21). Drake estimated the existence of about 10,000 civilizations just like ours somewhere in our vast galaxy.[1] This leads one to think: if that many *intelligent* life forms exist in the galaxy, there must be hundreds of thousands of *primitive* life forms that also exist. There is one accessible planet in our solar system that may hold the true answer buried somewhere in its red abyss: Mars.

This paper will use Mars as a case study to analyze the methodologies that researchers and the government alike are using to explore, evaluate, and define extraterrestrial life. This paper will also answer these following questions: What conditions are necessary for Martian life? How are researchers using life on Earth as a template for extraterrestrial life on Mars? What environments would be ideal for life's existence on Mars? What biosignatures or life clues are researchers searching for? What technologies are researchers using to examine the Red Planet?

In order to begin the search for life elsewhere, we must first understand how life exists on Earth. As the research will show, there is much debate on where life begins and where life ends. There is even debate over the very definition of life. The only way to understand life is to follow the trail of bread crumbs it leaves behind. Researchers do this by looking at biosignatures and biomarkers such as fossils. Scientists can use these same clues to search for life on Mars.

By connecting fossils to an environment, scientists can begin to understand the basic conditions necessary for life. Earth holds a number of extreme environments, and yet life is able to thrive in them. This could suggest that life might be able to survive on a planet with such extreme conditions as Mars. Mars and Earth may be worlds away, yet their formations and landscapes have huge similarities. Water has left its footprint all over the Martian surface and has been found to still exist there in large quantities. In fact, about 3,000,000 km^3 of frozen water is trapped on the Martian poles—enough water to cover its entire surface with a 25-meter-deep ocean (Gargaud, M., López-Garcìa, P., & Martin, H., 2011).[2] This leads researchers to believe that life on Mars could have been—and still could be—possible.

Researchers not only must be able to understand the boundaries of life, but also must set a criterion to the evidence that they find. How can researchers prove that there once was life on Mars? A controversy over an ancient Martian meteorite has researchers arguing over what biomarkers can be confirmed as evidence. The scientific method and consensus are essential in order to prove extraterrestrial life.

To explore the foreign landscapes of Mars, the National Aeronautics and Space Administration (NASA) and the Jet Propulsions Laboratory (JPL) have invented rovers, satellites, and landers. This sophisticated equipment holds the power to observe, analyze, and explore Mars. The main missions of these engineering wonders are to find out if Mars is a habitable place (NASA, 2013). NASA has large plans for building a complete history of the Red Planet.

What is Life?

For many, defining life proves difficult because it is hard to classify the diverse range of life on Earth under one umbrella. According to the *Random House Dictionary of the English Language*, the definition of life is “the condition that distinguishes organisms from inorganic objects and dead organisms, being manifested by growth through metabolism, reproduction, and the power of adaptation to the environment through changes originating internally" (Flexner, 1987). Therefore, life is defined by three key actions: growth, reproduction, and interaction with the environment. These key actions are specific to terrestrial life; however, Martian life will be held to the same standard. Life on Mars is going to be defined by our perspective of life on Earth. Therefore, we need to set a base understanding of life before we can attempt to search for it 140 million miles away.

In humanity's brief existence (relative to the history of Earth), we have so far discovered that life first began about four billion years ago (Ward, 2000). These primitive life forms would have been bacteria or archaea (Ward, 2000). From these simple-celled organisms, we evolved into millions of different complex species. But what unites all of these living things? According to Ward and Brownlee (2000), all life on Earth is based around deoxyribonucleic acid, or DNA. DNA is a molecule that is composed of four nucleobases: adenine, cytosine, guanine, and thymine. DNA acts as the code that allows life to grow, reproduce, and respond to the environment around it. The very fact that all life is biochemically the same is evidence that we came from the same ancestor (Jones, 2008, p.45).

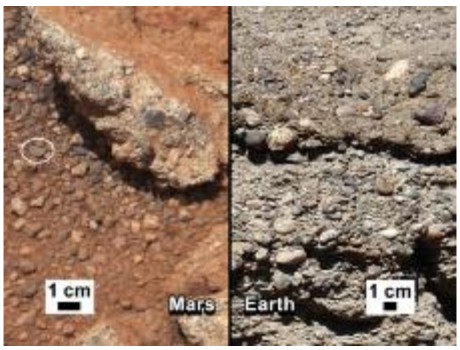
If we were to use Earth as a model for life on Mars, we could begin to search for microorganisms. Since life on Earth started as very simple-celled organisms, it is perhaps very likely that life on Mars began the same way. However, is it safe to assume that Martian life originated similarly to terrestrial life? To answer this question, we must step back and peer into the formation of the planets and the environments that they harbor.

Environments on Earth and Mars

It is essential to understand what kind of environments support life. If the environments on Earth are similar to those on Mars, then we can expect that life could have once existed there. The environments on Earth and Mars are products of their formation and evolution as celestial bodies. The two planets are similar in many aspects, yet both planets have evolved to be quite different from each other. The key difference between the two planets is their atmospheres. One has allowed a stable greenhouse effect that keeps the surface temperature warm, while the other has a decayed atmosphere that causes temperatures on the planet to plummet (Gargaud, M., López-Garcìa, P., & Martin, H., 2011, p.241). However, researchers have found evidence that liquid water may have once covered the red planet. Liquid water is necessary for life and has even become NASA's primary theme in their "Follow the Water!" search for life on Mars (NASA, 2013).

Earth and Mars share several similarities in their formation and composition. Around 4.6 billion years ago, the two planets began to take shape from a thin disc of dust and gas (Jones, 2008, p.25). They are both comprised of the same basic elements and molecules (water included), and are both within the habitable zone of the solar system—neither too close nor too far from the Sun. The habitable zone allows the perfect conditions for liquid water and by extension, life (Jones, 2008). Both planets were also exposed to geothermal activity, which isessential to releasing carbon to the environment. All life forms are based on the element carbon. Basiuk (2010) stresses the significance of carbon in life processes such as evolution and reproduction (p.2). With the perfect "Goldilocks conditions" of liquid water and a carbon rich environment, the conditions for forming life are ideal (Jones, 2008, p.72). Evidence shows that Mars may have been more like Earth hundreds of millions of years ago.

The Martian terrain is littered with geographical evidence of ancient running water. Several of the terrain features observed on Mars are similar to mineral deposits and formations from running water on Earth, such as lakes, gullies, deltas, rivers, canyons, and deposits in craters. NASA's recent Curiosity Rover mission has discovered a Martian river bed (shown below). University of California, Berkeley investigator William Dietrich claims that "from the size of gravels [the river] carried, we can interpret the water was moving about 3 feet per second, with a depth somewhere between ankle and hip deep" (NASA, 2012).



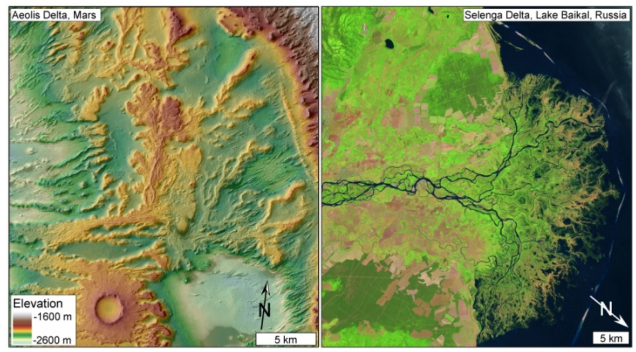


***Figure 1*. Evidence of Ancient Martian Liquid Water (NASA [Photograph]. 2012) *Figure 2*. (NASA [Photograph]. 2013) The figures above show the similarities between geographical features on Mars and Earth. On the left is the comparison of river beds, and on the right is a comparison of deltas.**

The striking similarities between the Martian and terrestrial geographical features serves as profound evidence that liquid water did once exist on Mars. Therefore, ancient Mars had the necessary environments to harbor life. Microbial fossils could exist under these ancient remnants of water. Jones (2008) even suggests that "if, as seems likely, water exists at no great depth in Mars, then life could exist at no great depth too" (p.79). This means that Martian life might be found in the planet's sub-terrain.

Why did all of Mars' liquid water become permafrost? According to J.P. Bibring, the loss of liquid water could have occurred with the loss of Mars' magnetic field. He explains that with a loss of the magnetic field, Mars would be subjected to the Sun's bombardment of electromagnetic waves, and as a result, its atmosphere would deteriorate. A decreasing atmosphere would cause the planet's temperature to drop and all the water on the planet to freeze

(Gargaud, M., López-Garcìa, P., & Martin, H., 2011, p. 241). In contrast, Earth has maintained a healthy magnetic field and a thick atmosphere that both preserve its liquid water. Liquid water on Earth, and quite possibly on early Mars, has served as the medium for growing life.

Evidence Needed to Prove Martian Life

On December 27, 1984, a rock that was discovered in the icy desert of Antarctica started one of the biggest controversies in astrobiology and reignited humanity's quest to find life on Mars. This rock was an SNC-class meteorite, named ALH84001, which was launched off the surface of Mars by a massive impact event and eventually crash landed here on Earth (Sawyer, 2006). NASA astrobiologists McKay et al. (1996) found what they claimed to be "evidence for primitive life on early Mars" inside ALH84001, but they were quickly shunned by the scientific community. This not only set the scientific community on its head, but also initiated debate over which facts are necessary to prove Martian life exists.

McKay et al. had discovered two biomarkers (chemistry usually found in living organisms) in the meteorite: an abundance of "polycyclic aromatic hydrocarbons (PAHs)" and several "carbonate globules" (1996, p.924). PAHs are organic molecules that are the "product of cellular decay" and are the contrails that follow life (Sawyer, 2006, p.99). The presence of PAHs suggests that microbial life once existed in the Martian meteorite. The carbonate globules were discovered with the PAHs. According to McKay et al., they were similar to those created by bacteria on Earth; this is a clue that they are also associated with microbial life. Together, these findings warranted McKay et al.'s belief that they had sufficient evidence to prove early Martian life existed.

Immediately after McKay et al. revealed their findings, criticism over the microfossils emerged and sparked a debate over the Martian meteorite that continues to this day. This controversy highlights the need for specific guidelines for proving Martian life. Cady et al. (2012) mentioned two major root guidelines in their research paper: 1. the fossil must originate from Mars, and 2. the fossil must be biogenetic or of biological origin. The only problem with these basic guidelines is the general lack of consensus on which fossils are biogenetic. Cady et al. explain:

> The ongoing controversy regarding the claim of microfossils in Martian meteorite ALH84001 exemplifies the difficulties encountered in proving biogenicity on the basis of morphological characters that are not unique to microfossils. Indeed, the need to be able to distinguish the biogenically produced characteristics of morphological microfossils from those produced non-biologically. It is equally important to know how to distinguish between biologically and non-biologically produced stromatolites. (p.352)

In other words, the ability to distinguish between biogenic fossils and pseudo-fossils (non-biological) is needed before Martian life can be verified.

Cady et al.'s (2012) research also distinguishes between two morphological fossils that "reveal traces of microbial life": cellularly preserved microorganisms and stromatolites.[3] Cellularly preserved microorganisms contain biomarker compounds and minerals, displaying distinct organic characteristics. Stromatolites are laminated, microbially influenced sedimentary structures or microbial cells that have been completely replaced by minerals, as pictured below.

***Figure 3*. Stromatolites (Awramik, January 01, 2006). Pictured above is a stromatolite from Strelley Pool Chert, West Australia. The scale bar is ten centimeters.**

However, Cady et al. (2012) state that stromatolites are not reliable as evidence for life, because there is no distinction between those that are produced biologically and those that are not (p.352). This means that stromatolites have an ambiguous biogenicity, and that the only morphological fossils that can confirm Martian life must be cellularly preserved.

Stanley M. Awramik, a UCSB stromatolite researcher, would disagree with the conclusions of Cady et al. In his peer-reviewed article, titled "Respect for Stromatolites" (2006), he argues that stromatolites are in fact of microbial origin and are biogenetic. He bases his argument on research from a report of 3,430-million-year-old stromatolites by Allwood et al. (2006). Awramik (2006) argues that "carbonate platforms with stromatolites are common in the geological record", and that "sediment-grain compositions and textures of the stromatolites cannot be explained exclusively by mechanical processes" (p.700). Awramik states that since a long history of organic molecules and stromatolites exists, it suggests that the formation of stromatolites has to be influenced by biotic processes. In other words, since organic molecules are found in stromatolites, it strongly indicates that they are formed from the lamination of microbial organisms. This debate over stromatolites shows that the search for life on Mars is in fact dependent on the definitions of life on Earth. Without a consensus or clear guidelines on fossil biomarkers, the proof that life existed on Mars may be hard to find.

An alternative biomarker that can be used in the search for Martian life is chirality. A molecule is chiral when its components have "nonsuperimposable mirror images". For example, your hands represent chirality because "one hand cannot be turned to make it identical to the other" (Zumdahl, 2010). Like your hands, molecules come in two forms: left (L form) and right (D form) as shown below.

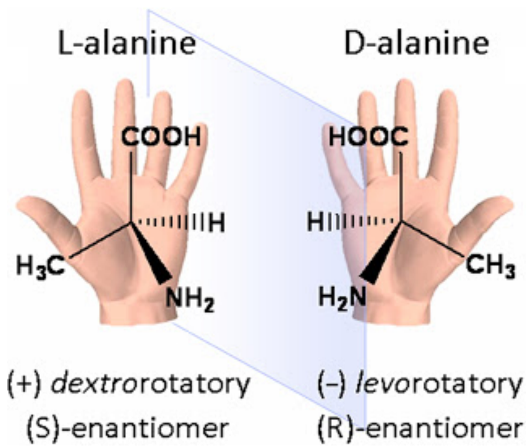


***Figure 4*. Chirality and Alanine (2012). The image above shows the L and D forms of the molecule alanine. The analogy of the hands is used to help show that the molecules are nonsuperimposeable mirror images.**

This is a major clue to note because the chemistry of life is structured with certain chiral patterns. Its importance is noted by Jones (2008):

> A striking feature of life on Earth is that in all DNA and all RNA, the sugars in the spines occur only in the D form, and very nearly all amino acids in proteins occur only in the L form. The other forms are of no biological use at all. (p.53)

The chirality of life is an important biomarker. If traces of these certain chiral molecules are found on the surface of Mars then it can serve as evidence for the existence of life.

However, a report by the National Research Council (2007) to NASA and the National Science Foundation noted a problem with using chirality as a biomarker: "Once an organism dies and its biochemicals are released into the environment, their chiral purity (and optical activity) may or may not persist depending on the relative chemical stability of the bonds in the vicinity of the chiral center" (p.80). This is an issue because if the organic molecule does not have a stable bond, then proving chirality may be difficult. In addition, if these molecules decay, then chirality cannot be a useful biomarker for ancient Martian life.

Current Search Efforts & Future Efforts

Missions to Mars are a marvel of engineering, science, and technology. NASA has flown 15 missions to Mars since 1964; they include 12 satellites, five landers, and four rovers (NASA, 2013). Most of what we understand about Mars came from these missions in the past 50 years. The information these missions uncovered has changed our view of the Red Planet from a dry, barren wasteland to an environment full of opportunity. These NASA missions inch us closer to discovering whether Martian life did exist. The National Research Council (2007) puts it best: "No discovery that we can make in our exploration of the solar system would have a greater impact on our view of our position in the cosmos or be more inspiring than the discovery of an alien life form, even a primitive one" (p.84).

The most recent mission, Mars Science Laboratory (MSL), landed a two-ton Curiosity Rover inside Gale Crater. Amongst the mission goals were three biological objectives: 1. to analyze organic carbon compounds, 2. to inventory chemical building blocks of life, and 3. to search for biosignatures (JPL, NASA, 2012). To accomplish this task, Curiosity was retrofitted with several technologies including a robotic arm, cameras, spectrometers, radiation detectors, environmental sensors, and atmospheric sensors. It is essentially a nuclear-powered, radio-controlled laboratory on wheels. So far, the rover has discovered evidence of an ancient Martian river bed and completed its first drills on Mars. NASA's primary target is Aeolis Mons, a layered mountain that can provide insight into past history of the planet (Willumsen, 2012). The rover has the ability to test samples of the mountain for organic compounds. Curiosity (shown below) is still currently in operation on Mars.

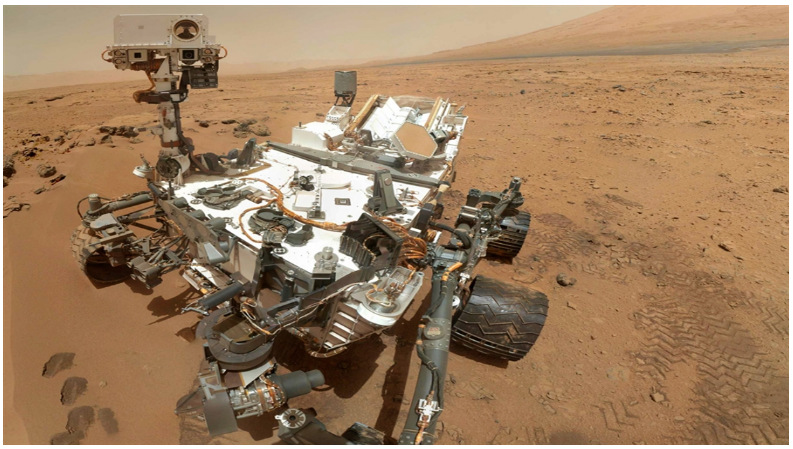


***Figure 5*. Curiosity (NASA, 2012). Pictured above is a self-portrait of the Curiosity Rover in the Gale Crater on Mars. The photo was taken using its Mars Hand Lens Imager.**

Future NASA missions plan to continue seeking for signs of life and to begin preparing for human exploration. The proposed plans are to send two new satellites, one lander, and two new rovers to the Red Planet. NASA intends to add deep-terrain drilling capabilities to the lander (appropriately named InSight) in order to investigate the Martian subsurface (NASA, 2013). This mission would hopefully be able to solve whether liquid water exists beneath the surface and perhaps even life. The missions to Mars in the past fifty years have been flybys, orbiters, landers, and rovers; in the future, NASA plans to send airplanes, balloons, and subsurface explorers and to conduct sample returns to Earth (NASA, 2013).

Conclusion

As shown by this paper, the search for Martian life is difficult and requires extreme patience. The answers to our most deeply rooted questions do not just simply lay at the edge of our finger tips, but are buried beneath the Martian terrain. In order to douse the firestorm of our curiosity, we must dig our nails deep into the dirt and find the evidence. This endeavor may run the clock, but if we look back at the progress accomplished in the past 50 years, we can hope that the answers to our questions may come in the near future.

One way to search for the truth is through the process of collaboration and debate. If researchers did not question their colleagues, then how could they ever find the mistakes hidden in the masses of their data? For example, the active debate on the biogenecity of stromatolites is a necessary consequence in the search for truth. If the scientific community did not object to McKay et al.'s findings on ALH84001, then the truth may have been glossed over. It is in the manner of analyzing and synthesizing data that we can come to share and contribute to the journey.

The search for Martian life has caused us to look at and define ourselves. By using the resources around us, we create the pieces to fit the puzzle together. The Earth holds several prime examples of diverse and remarkable life; it is rational to believe life must exist elsewhere. It is in the human intuition to say, “If it is possible here, it is possible over there!” However, it is ultimately in the human curiosity that we actually go “over there” and see for ourselves. From the safety of land, we peered and shook our heads at what seemed to be an endless ocean, yet we crossed and found new worlds. From the ground, we stared at the birds in what seemed to be hopeless jealousy, yet we created our own wings and began to fly. From the rim of a telescope, we gazed in awe to what seemed an unreachable task, yet we took a giant leap and landed on the

Moon. As explorers we now probe this very new frontier of Mars, and yet we know, given the time and the effort, that we will find the very truths we have been searching for all along.

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Endnotes

[1]For more information on the Drake Equation visit the BBC webpage cited in the references above.

[2]This fact was cited from Plaut *et al.*, 2007 in J.-P. Bibring's section "Water on Mars" on page 236 in Gargaud, M., López-Garcìa, P., & Martin, H. (2011) referenced above.

[3]Morphology is the study of the form of living organisms and the relationships between their structures.